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Fuel Properties of Palm Oil Biodiesel and Its Blends With Diesel

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ABSTRACT

Palm oil biodiesel was produced from two varieties of the oil palm, the Dura (native variety) and the Tenera (improved variety), by the process of transesterification. The Dura palm oil biodiesel, indicated as B_1100 and the Tenera palmoil biodiesel, B_2100, were tested to determine some fuel properties such as density, kinematic viscosity, flash point, pour point, cetane number (CN) and heat of combustion or calorific value, using the American Standard Test and Measurement (ASTM) methods and specifications. The Nigerian National Petroleum Corporation (NNPC) diesel, the Automotive Gas Oil (AGO) was used as the reference fuel. Also, the blends of the two types of palm oil biodiesel with diesel at 10 %, 20 %, 30 % and 50 % biodiesel inclusion were tested for the same fuel properties. The specific gravity (S.G.) at 15 °C of B_1100 was 0.8855 and that of B_2100 was 0.9122 as compared with diesel of 0.8709. The Dura biodiesel has met the international standard, which stipulates the range as 0.86-0.90. The specific gravity and the API gravity (both at 15 °C) of all the blends with diesel, especially at 10 and 20 % biodiesel inclusion were about the same as that of the diesel. The kinematic viscosity of B_1100 was close to that of diesel while that of B_2100 was higher. All the blends with diesel, especially 10-30 % biodiesel inclusion were like diesel and met ASTM specifications of the range, 1.60-5.50. The flash point and the pour point followed the same trend, with the blends exhibiting similarities almost exactly with diesel. Dura biodiesel had the highest CN of 51.12 while Tenera had the lowest, 42.01. Diesel had CN of 45.7. All the blends had CN higher than that of diesel. The high CN values indicate the high level of auto-ignition of these fuels, desirability in diesel fuel. The calorific value of the pure biodiesels were a bit lower than that of diesel but the blends, 10 & 20 % biodiesel inclusion, had higher heat contents than diesel.

Key words: Dura, palm oil, biodiesel, Tenera, biodiesel blends, fuel properties.

Introduction

Dr. Rudolph Diesel, who built the first Compression Ignition (CI) engine, used vegetable oil to run his engine. He exhibited this at the 1889 world's fair in Paris, France and also at 1900 Paris exposition, when he used peanut oil to run his diesel engine [1, 2]. Anon [3, 4], reported that crude palm oil was also used in running diesel engine.

Diesel, petroleum-based fuel and a by-product of the gasoline (petrol) manufacturing process, was found to have characteristics that were relatively similar to vegetable oil on which the diesel engine was run. This inexpensive by-product, as of then, became the fuel of choice for diesel engines. Nearly all researches which followed for many decades, focused on how to make diesel engine operate on petroleum-based diesel fuel [5]. However, in 1912, Rudolph diesel stated thus, "the use of vegetable oil for engine fuels may seem insignificant today, but such oils may become in the course of time as important as petroleum and coal- tar products of the present time" [6]. Today, his statement has become real because as petroleum resources are fast depleting and the product being scarce, much attention is now given to the vegetable oil based fuel, the biodiesel.

Biodiesel is obtained from vegetable oil through a chemical process called trans-esterification. It is no longer the crude vegetable oil used by Rudolph diesel in his diesel engine but refined to reduce cold-starting problems and bring its characteristics similar with that of petroleum diesel. It is an alkyl ester.

Biodiesel development has become an important issue today because of the crucial role of the diesel engine in productive economy. The diesel engine is the most efficient power plant of all known types of internal combustion engines, having fuel efficiency of about 25% more than petrol engine [7]. It is also sturdier and more durable than the petrol engine. Because of these advantages, the transport and construction industries depend greatly on diesel engines. Marine engines, heavy electricity generating plants, farm machinery, etc, are of diesel engines.

Therefore if the supply of diesel is cut, there will be crisis in many sectors of the economy, including agricultural sector. This is the reason why many nations are interested in biodiesel development for possible diesel fuel replacement in such circumstances. Apart from being a suitable replacement to diesel, it is also renewable and environment friendly. It contains about 10% oxygen, making it naturally oxygenated fuel [8]. It is therefore a cleaner burning fuel with reduced emissions. It is also used as blends with diesel to cut emissions. Dunn [7] stated that the US Environmental Protection Agency (EPA) had confirmed that biodiesel significantly reduces regulated exhaust emission of unburned hydrocarbons such as Carbon Monoxide (CO), particulate matter (pm), at all blend levels with petrol-diesel.

The need to control pollution processes, especially in African countries which have proved relatively incapable of maintaining acceptance level of environmental protection, and the need to explore more sustainable energy production claims, greatly foster interests in renewable raw materials for such energy production.

Vegetable oils have excellent energy potentials for use in non-food application. The relative low quality requirement in producing energy from vegetable oils and the availability of large quantities of vegetable oils from so many crops provide further reasons for interest in biodiesel production. Such crops which produce oil directly are soybean, sunflower, rapeseed (Canola), oil palm, *Jatropha*, etc. Among them, the oil palm is the highest yielding oil producer, having yields of about 3000kg/ha annually, with good cultural practices [9].

Gascon *et. al* [10] have also stated that the oil palm produces more oil per unit area (5-7 tons/ha) than any other oil crop. Furthermore, the oil palm is a permanent crop which can remain productive for up to 80 years. Once it is planted, there is continuous supply of oil, unlike many other oil crops, such as soybeans, sunflower, etc, which are planted annually with much labour.

It could be reasonably argued that the use of palm oil as motor engine fuel may present a source of conflict or competition with its use as a base for food, cooking oil, industrial products such as soaps, candles, creams, etc. The fact is that fuel is needed as a source of energy for production. Even when petroleum oil is in abundance as in Nigeria, the products are still very scarce and costly and sometimes not available in the rural areas when it is needed for agricultural processes. The United States of America today is producing commercial quantity of ethanol as petrol replacement fuel from corn, a very important food crop in that country. The strategy is that the US government is encouraging farmers to plant more corn for food feed and for ethanol production. Nigerian government can encourage farmers to plant more oil palm, so that there will be oil for food and for fuel.

After all, if biodiesel is to be produced only from non-food energy crops, such as Jatropha, much land which would have been used for food crops would be taken over by this crop. This will also have negative effect on national food security. Whereas if that land were to be used for oil palm plantation, some of it will go for food production while others can go for fuel production.

Vegetable oil biodiesel has recently proved to be one of the alternative reliable sources of providing continuous fuel supply needed on a typical mechanized farm. Studies have shown that diversion of just 10 % of the total hectares of a farm of vegetable oil production to biodiesel production can provide the farm fuel needs for mechanization [11]. This practice can be adopted in a mechanized oil palm plantation. There are great potentials for the production of biodiesel from oil palm. The oil palm is a local feedstock and it may be a more reliable source of vegetable oil than the exotic oil plants.

In this work, biodiesel was produced from palm oil obtained from two varieties of the oil palm, namely, the native variety (Dura) and the improved variety (*Tenera*). Fuel properties of the palm oil biodiesel and its blends with diesel at various proportions were investigated. The studies on blending was important so as to determine appropriate blending levels for good quality fuel, since biodiesel is used mainly for blending with diesel. Diesel was used as the reference fuel.

Materials and Methods

Biodiesel was produced from palm oil obtained from two varieties of the oil palm, the Dura (native variety) and the *Tenera* (improved variety) by trans-esterification. In the process, palm oil was reacted with alcohol, methanol, in the presence of a catalyst, sodium hydroxide. The quantity of sodium hydroxide required was obtained by titrating a solution of sodium hydroxide against a solution of palm oil in isopropyl alcohol.. The reaction took place in a locally fabricated batch reactor, stirred at about 900 rpm for 2 ½ h. The resultant biodiesel was separated from glycerol, a by-product of the production process. It was washed several times in water to remove sodium impurities and bring the pH to about 7.0. The biodiesel was dried by heating to remove moisture, cooled and used as fuel. Samples of the biodiesel and its blends with diesel at various proportions were used for the determination of fuel physical and chemical properties.

Blends of Dura palm oil biodiesel were denoted by B_1, followed by a number which indicates the proportion or percentage of biodiesel inclusion in the blend. For example, B_1 20 indicates 20% Dura palm oil biodiesel and 80% diesel in the blend. Similarly, B_2, is followed by a number that also shows the proportion of Tenera palm oil biodiesel in the blend with diesel. The Nigeria diesel, Automotive Gas Oil (AGO) was the reference fuel. Facilities of Shell Petroleum Development Company (SPDC) laboratory, Port Harcourt, Nigeria, were used for some of the tests in accordance with the methods outlined by the American Standard of Tests and Measurements (ASTM). The tests included specific gravity at 15°C, API gravity at 15°C, and kinetic viscosity at 40°C. Others were flash point, pour point, Cetane Number, and heat of combustion or calorific value. The mid-point temperature distillation method was used in the determination of Cetane index, an estimation of Cetane Number. Bomb calorimeter was used for the determination of heat of combustion or calorific value.

Results and Discussion

Results:

Table I shows the fuel properties of palm oil biodiesel and its blends with diesel from 10% biodiesel inclusion to 50%. Nigerian National Petroleum Corporation (NNPC) diesel, the Automotive Gas Oil (AGO) was the reference fuel. Thus, there are 10 candidate fuels consisting of pure (100 %) Dura and Tenera palm oil biodiesel and 4 blends of each of them. Their properties were investigated as recorded

Discussion

Fuel Density

There are two aspects, specific gravity (S.G) at 15°C and API gravity at 15°C. The ASTM minimum specification of S.G. for diesel fuel is 0.820. The S.G. of AGO is 0.8709

Pure biodiesel

The candidate fuels, Dura palm oil biodiesel, $B_1$100 and Tenera palm oil biodiesel, $B_2$100 have S.G. of 0.8855 and 0.9122, respectively. Dura palm oil biodiesel is lighter than Tenera. It is very close to diesel in density. The international standards of S.G. for biodiesel is generally in the range, 0.86-0.90 (National standards for biodiesel @ http://journeytoforever.(org.) [12]. Therefore, Dura palm oil biodiesel has met this standard. The Tenera palm oil biodiesel is still acceptable at that range. Similarly, the API gravity maximum specification is 39 degrees. AGO is at 31 degrees while Dura and Tenera biodiesel, have 28.30 and 23.60 degrees, respectively. This also shows that Dura palm oil biodiesel is close to AGO in density.

10 percent palmoil biodiesel blend with diesel (10/90, biodiesel/diesel blend).

The S.G. for 10% Dura palm oil biodiesel blend (10/90-biodiesel/diesel blend), $B_1$10, is 0.8719 while that of Tenera, $B_2$10, is 0.8749. These values are almost that of AGO, which is 0.8709. Also, the API gravity of $B_1$10 is 30.8 degrees and that of $B_2$10 is 30.2 degrees. These values are almost the same with that of AGO, 31.0. Therefore the blends, $B_1$10 and $B_2$10 are just as AGO.

20 percent palm oil biodiesel blend with diesel (20/80, biodiesel/diesel blend)

The S.G. for Dura palm oil biodiesel blend at 20 %, $B_1$20 is 0.8735 while that of Tenera is 0.8783. These values show that 20 % biodiesel blend is just as AGO. Again, the API gravity values show that $B_1$20 is 30.50^0 and $B_2$20 is 29.60. These are also very close to 31, the value for AGO. During engine test performance, they were just as AGO.

30 percent palm oil biodiesel blend with diesel (30/70, biodiesel/diesel blend).

The S.G for $B_1$30 is 0.8783 while that of $B_2$30 is 0.8817. They are within the range of international standard for biodiesel density, hence they are good fuels. The API values are 30.30 and 29.0^0 for $B_1$30 and $B_2$30, respectively. They are quite close to 31, the value for AGO.

50 percent palm oil biodiesel blend with diesel, (50/50, biodiesel/diesel blend).

The S.G. for $B_1$50 is the same for $B_2$50 at 0.8779. These fuels did not have cold starting problems when run in the engine [13]. $B_1$100, with slightly higher value, did not have cold starting problem too. The API values are the same also for both fuels, with a value of 29.70 degrees.

Table 1: Some fuel parameters of palm oil biodiesel and its blends with Nigerian diesel, AGO, compared with those of AGO.

Parameters	**ASTM method**	**ASTM specification**	**NNPC Diesel (AGO)**	**100% palm oil Biodiesel**		**10% palm oil Biodiesel blend**		**20% palm oil Biodiesel blend**		**30% palm oil Biodiesel blend**		**50% palm oil Biodiesel blend**	
				B_1100 (Dura)	B_2100 (Tenera)	B_110 (Dura)	B_210 (Tenera)	B_120 (Dura)	B_220 (Tenera)	B_130	B_230	B_150 (Dura)	B_250 (Tenera)
Specific gravity at 15 °C	D1298	0.820 minimum	0.8709	0.8855	0.9122	0.8719	0.8749	0.8735	0.8783	0.8745	0.8817	0.8779	0.8779
API Gravity @ 15 °C	D287	39 max.	31.0	28.30	23.60	30.80	30.20	30.50	29.60	30.30	29.0	29.70	29.970
Kinematic viscosity @ 40 °C (cst)	D445	1.60-5.50	4.9	7.65	33.10	5.20	5.80	5.40	6.85	5.43	8.33	.96	5.80
Flash point (°C)	D93	52 min.	126.7	178.7	>200	126.70	121.70	129.7	124.7	127.70	125.70	134.80	133.80
Pour point (°C)	D97	3 max.	<-26	10.0	7.2	<-26	<-26	<-26	<-26	-3.90	<-26	-1.1	-1.1
Cetane number (CN)	D976	35 min.	45.70	51.12	42.01	48.60	47.62	48.26	47.13	48.20	48.26	47.98	50.61
Heat of combustion (kJ/kg) (gross)	Bomb calorimeter	-	41,478.30	38,131.0	38,000.0	41,217.40	41,978.27	42,282.61	41,195.66	40,300.00	39,634.58	38,434.83	38,913.05

Thus AGO, with its upper density limit at 0.8709, contains heavier aromatics than no.2 diesel with its upper density limit at 0.84. This may account for the former being a heavy pollutant than the latter or diesel of many other developed nations, which also have lower upper density limits. However, biodiesels are clean fuels which do not contain aromatics as diesels. Therefore they are not pollutants. They are oxygenated fuels which burn properly to reduce emissions. This is why they are blended with diesels to cut down emissions. Therefore, AGO needs blending with biodiesels to reduce emissions in diesel engines and hence reduce environmental hazards.

Kinematic Viscosity at 40°C

The ASTM specification for the kinematic viscosity in diesel fuel is that it should be in the range of 1.60 – 5.50 cst. The kinematic viscosity for diesel is 4.9cst. The blends, $B_1$10, $B_1$20, $B_1$30, are all within this range. Other blends are also not far from the specifications. It is only 100 percent Tenera palm oil biodiesel ($B_2$100) that has a very high value of 33.10 cst. It is known that high viscosity reduces fuel flow rate. $B_2$100 had cold-starting problem during engine test performance because of this high viscosity. It was difficult to start the engine even when left for few hours. AGO was used to start the engine before running it with $B_2$100 and at the end of running, AGO was also used in flushing the engine (Warm-up and cool-down). This is characteristics of many known biodiesels. However, Dura palm oil biodiesel ($B_1$100) did not have this cold-starting problem in the engine. With it, the engine started easily just as with diesel, even when it was left for up to one week. Since all the blends of both Dura and Tenera palm oil biodiesel with diesel had viscosities lower than $B_1$00, then they will not have cold-starting problem. Therefore the blends are good fuels when viscosity is considered.

Flash Point (°C)

The ASTM minimum ignition temperature for highly flammable liquids is 52°C (flash point). That of AGO is given as 126.7°C. All the palm oil biodiesel blends with AGO have flash points close to that of AGO too. Some, such as $B_1$10, have exactly the same value. Some, such as $B_2$10, $B_2$20 and $B_2$30, have values very slightly lower. The pure biodiesels, $B_1$100 and $B_2$100 have higher values with $B_2$100 much higher. These values for biodiesels and their blends indicate safe handling and storage for they cannot ignite easily below 100°C. Therefore biodiesel and their blends with diesel are good fuels when safety is considered.

Pour Point

The ASTM upper limit pour point for diesel is 3°C but the pour point for AGO is < - 26°C, indicating that it can be used to run engines at very low temperatures. The pour points for pure Dura palm oil biodiesel and pure Tenera palm oil biodiesel are 10°C and 7.2°C, respectively. They cannot be used at very cold conditions of less than these temperatures. Most of the time, tropical conditions do not go down to these temperatures; hence they are useful fuels for the tropics.

However, the blends, 10% to 20% palm oil biodiesel with diesel, all have their pour points as < -26°C, exactly the same as for diesel, AGO. $B_2$30 has the same value too. Other higher blends of 50% palm oil biodiesel still have pour points lower than ^{0}C. Therefore all palm oil biodiesel blends, up to 50% blend with diesel, can perform well under cold conditions. They have good cold flow properties.

Cetane Number (CN)

Table II: CN calculated from distillation points

Sample	Relative Density, ρ at 15 °C	1st Boiling Point Temperature, T1	2nd Distillation Point T50 (°C)	Calculated Cetane No. (CN)
B_1 10	0.8719	275 °C	316 °C	48.60
B_2 10	0.8749	274 °C	315 °C	47.62
B_1 20	0.8735	274 °C	317 °C	48.26
B_2 20	0.8783	262 °C	319 °C	47.13
B_1 30	0.8745	272 °C	319 °C	48.20
B_2 30	0.8817	270 °C	341 °C	48.26
B_1 50	0.8779	272 °C	326 °C	47.98
B_2 50	0.8779	290 °C	362 °C	50.61
B_1 100	0.8855	295 °C	355 °C	51.12
B_2 100	0.9122	274 °C	365 °C	42.01
Overheated or bleached $B_1$100		210 °C	310 °C	44.06
Diesel fuel	0.8709	265 °C	293 °C	45.70

Table II shows first boiling points and second distillation points of the different fuels which were used in calculating the Cetane numbers from equation 1.

The results show that the CN for diesel, AGO, is 45.70, while Dura palm oil biodiesel is 51.12 and the Tenera palm oil biodiesel is 42.01. Thus, Dura palm oil biodiesel with the highest CN of 51.12 is the preferred fuel as far as combustion requirement is concerned. The palm oil biodiesel and their blends with AGO had high CN values. They are therefore very good fuels for diesel engines which require self-ignition. When 5 fuels, diesel (AGO), $B_1$100, $B_2$100, $B_1$10, $B_2$10, were used for mechanical efficiency test in the diesel engine, this fuel, $B_1$100, showed the highest performance as shown in fig 1 [14]

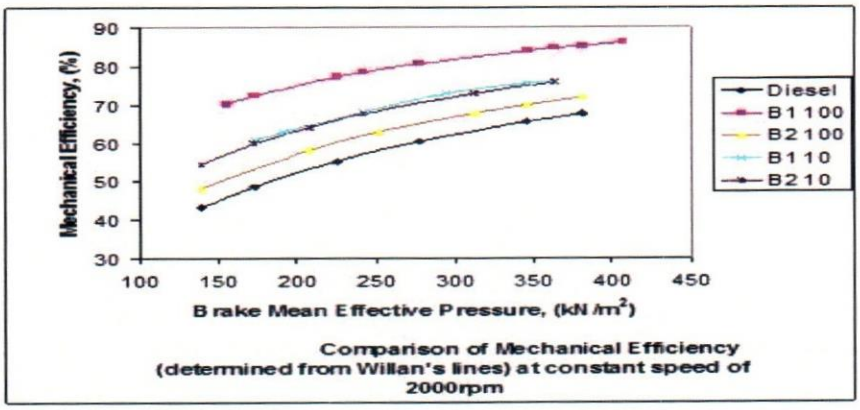
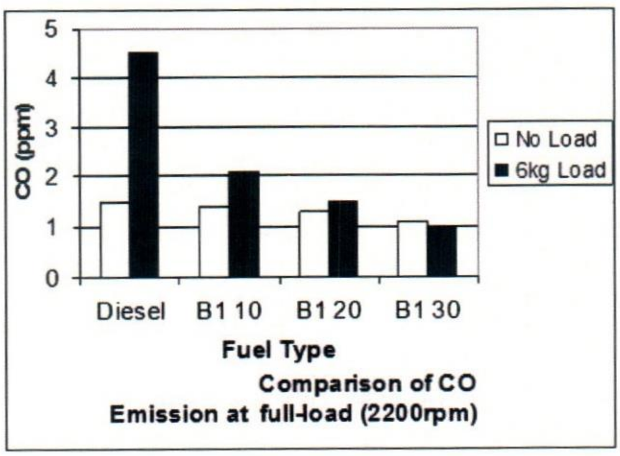


Fig. 1: Mechanical Efficiency of Diesel Engine Using Palm oil Biodiesel and Its blends with AGO as compared with AGO. Source: Ituen *et. al*, (2009)

It was again noted that Tenera palm oil biodiesel ($B_2$100) with the lowest CN of 42.01 had cold-starting problems. Therefore CN has much influence on fuel ignition. It is further observed that all the fuel blends have high CN values, much higher than that of AGO. This shows that blending diesel with palm oil biodiesel improves the CN of the blended fuel and therefore enhances better combustion process and power performance. Because of better combustion process, emissions are reduced in biodiesel and its blends with diesel as shown in Fig 2.



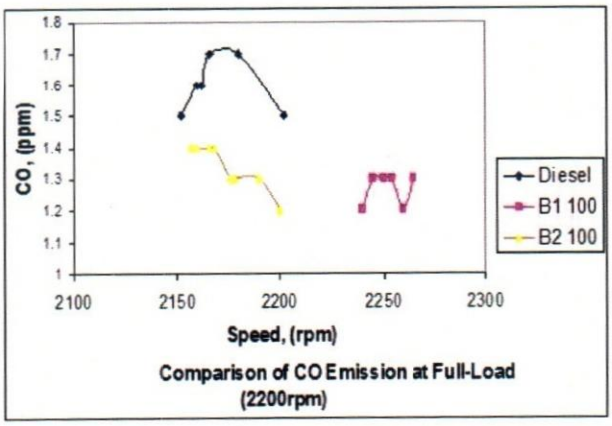


Fig 2: CO Reduction with Palm Oil Biodiesel and its Blends with Diesel Source: **Ituen, (2009)**

Dura palm oil biodiesel is seen to have reduced carbon monoxide (CO) emission more than both Tenera palm oil biodiesel and AGO. Its blends with AGO also shows more CO reduction than AGO [15].

Heat of Combustion (Calorific Value) kJ/kg.

The results show that AGO with a calorific value of 41,478.30 kJ/kg, had more heat content than the Dura and Tenera palm oil biodiesels which had 38,131.00 kJ/kg and 38,000.00 kJ/kg, respectively. This agrees with the assertion that the heat contents of biofuels are a bit lower than those of petroleum fuels because of bonded oxygen [16]. That is, biofuels are oxygenated fuels. It is noted that the heat contents of the blends, especially lower biodiesel compositions, were higher than that of diesel. This was seen as unusual because it was expected that the blends would have values in-between that of diesel and pure biodiesel. These higher heat contents were reflected in power performance curves for the blends which were higher than those of diesel and pure biodiesels as seen in Fig 3.

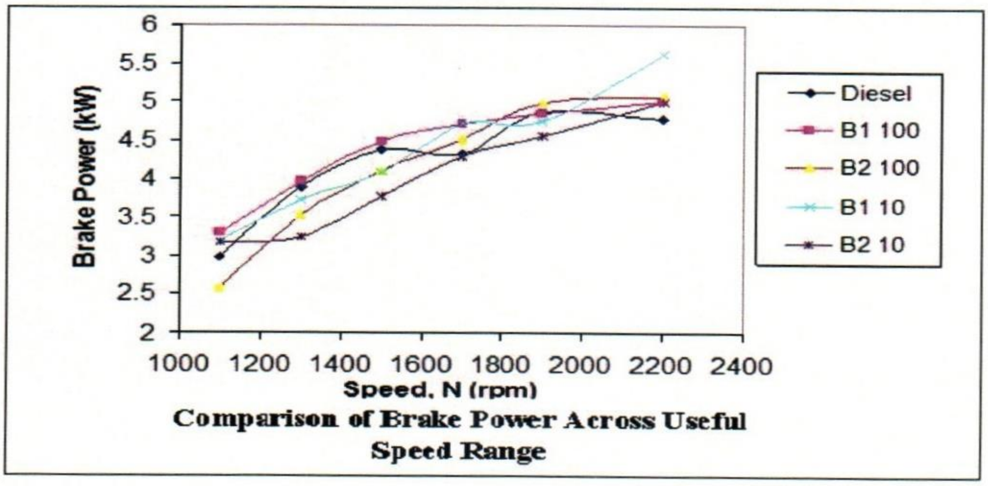


Fig. 3: Comparison of Brake Power Performance in the Diesel Engine with Palm oil Biodiesel and Its Blends with AGO. Source: **Ituen, (2008)**.

Brake specific fuel consumption {ability to convert fuel energy into mechanical work} test performance curve shown in Fig 4 was used to further assess the performance of the fuels. Dura blend $B_1 10$ was seen to perform the best by showing the lowest set of values [17]. Low brake specific fuel consumption gives high brake power output. This also has direct effect on fuel economy [18]. It is again observed that this fuel enabled the engine to sustain prolonged dynamometer loading more than others, including diesel. This ability to carry prolonged loading may be due to high calorific value, high cetane number and oxygen content. Therefore, it is fuel for heavy duty works.

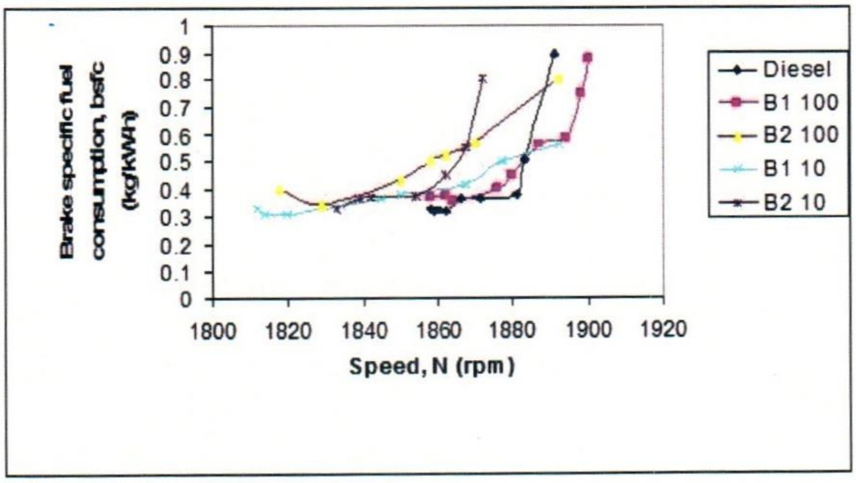


Fig 4: Brake Specific Fuel Consumption of Palm Oil and Its Blends with AGO. Source: **Ituen *et al* (2011)**

Further investigation as to the behavior of the Dura blend was carried out by temperature measurement. The blend, $B_1 20$ had a temperature of 28^0C, while $B_1 100$ and AGO, before blending, had temperatures of 30^0C and 31^0C, respectively [13] The drop in temperature indicated cooling effect of the blend and possible endothermic reaction, hence, higher energy bonding. If this reaction is peculiar with palm oil biodiesel, it means it has comparative advantage over other types of biodiesels. Table III shows engine pulley belt-breaking (burning) temperatures when the engine was run with the different fuels and the dynamometer loaded to the breaking points.

Table III: Engine-Pulley temperature at belt breaking (burning) point when using different fuels

Fuel	Engine Speed, N (rpm)	Pulley Temperature (^oC)
Diesel	2200	280
$B_1$100	2200	292
$BS_2$100	2200	288
$B_1$10	2200	265
$B_2$10	2200	260

The engine pulley temperatures were lower with the blends. This shows there was cooling of the engine by the blends. Blends of 10 to 20 % palm oil biodiesel with diesel are commended for higher heat content and cooling of the engine. Other higher blends of up to 50 % are still good fuels with sufficient heat contents and cooling effect.

Conclusion

Palm oil biodiesel has been found to have similar properties with AGO and hence it is a good diesel replacement fuel. Dura palm oil biodiesel was seen to compete closely with diesel in density, kinematic viscosity and flash point. It has a higher Cetane Number than diesel, a comparative advantage in combustion process. It was only lower than diesel in heat content.

The Tenera palm oil biodiesel was equally a good fuel but performed below AGO and the Dura palm oil biodiesel in terms of density, kinematic viscosity and Cetane Number.

The blends of both Dura and Tenera palm oil biodiesel, with AGO, up to 50 %, were very good fuels. The blends, especially at lower biodiesel compositions, had almost the same fuel properties with AGO. The blends $B_1$10, $B_2$10, $B_1$20, $B_2$20, had high heat contents and $B_1$20, $B_2$20, higher than that of AGO. The blends are used to cut down emissions in engines and hence contribute to safe environment. They are also known to cool and lubricate engines; hence they are called premium fuels

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